LANDING SITE AND TRAVERSE PLAN DEVELOPMENT FOR RESOURCE PROSPECTOR.

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Introduction: Resource Prospector (RP) will be the first lunar surface robotic expedition to explore the character and feasibility of in situ resource utilization at the lunar poles. It is aimed at determining where, and how much, hydrogen-bearing and other volatiles are sequestered in polar cold traps. To meet its goals, the mission should land where the likelihood of finding polar volatiles is high [1,2,3]. The operational environment is challenging: very low sun elevations, long shadows cast by even moderate relief, cryogenic subsurface temperatures, unknown regolith properties, and very dynamic sun and Earth communications geometries force a unique approach to landing, traverse design and mission operations.

Landing Site Identification: In addition to a high potential of volatile sequestration, a landing site candidate must meet engineering and mission operations requirements: sufficient solar access to power the rover over mission lifetime, sufficient visibility to ground stations for real time communications, manageable hazards such as slopes and block abundance, etc. A landing site must have acceptable slopes within the 3-sigma landing ellipse (200-m diameter); it should also have at least 48 hours of sun and DTE communications access to accommodate checkout, rover egress, and initial operations, with margin.

At this time, four landing sites are being used to study mission design and feasibility, two in the north and two in the south. These are shown in Table 1.

Table 1. Design Reference Mission Landing Sites

Pole	Site Name	Lat.	Lon.
SP	N. Nobile	85.194S	35.436E
SP	N. Shoemaker	87.185S	59.921E
NP	Erlanger	87.19N	29.119E
NP	Hermite-A	87.436N	-49.039E

Requirement Drivers: Resource extraction must be economical. So data is needed concerning distribution and accessibility to help determine if a resource and processing technique allows for positive Return on Investment (ROI), including Mass, Cost, Time, and Mission/Crew Safety. ISRU's economic viability depends on volatile distribution (including lateral and vertical extent and variability), volatile composition and form (H_2, OH, H_2O, CO_2, ice vs structural water, etc), nature and depth of overburden (how much mate-rial must be removed to access "ore"), and working environment (sun/shadow fraction, soil mechanics, trafficability, temperatures, etc.). The mission plan calls for the investigation of several different environmental zones for volatile sequestration:

Dry: Temperatures in the top meter expected to be too warm for ice to be stable.

Deep: Ice expected to be stable between 50-100 cm of the surface.

Shallow: Ice expected to be stable within 50 cm of surface.

Surface: Ice expected to be stable at the surface (ie., within some sufficiently cold Permanently Shadowed Regions, PSRs)

By characterizing the volatile resource attributes in these environments, RP will help address issues related to economic viability described above. A key is to develop predictive power for resource location and ore potential, in much the same way that characterizing promising sedimentary settings in oil and gas exploration is done.

Maps Needed for Study: Layers in a landing site and traverse planning tool must include the following: *time-varying* sun and comm access; slopes (digital terrain models); water ice stability depth models for both paleo-pole and present-day conditions; hydrogen concentration maps; permanently shadowed regions; LROC NAC photomosaics; LRO Diviner blockiness or rock abundance measure.

Currently, the LOLA DEMs we use have 20-m posting, which is sufficient for many mission planning purposes. For detailed traverse planning involving hazard avoidance at smaller scales, higher resolution is much desired. Initial efforts with a shape-from-shading approach using LROC NAC imagery are very promising (see abstract by Oleg Alexandrov and Ross Beyer, this meeting).

Traverse Design Tool: To incorporate the static and time-varying constraints on mission design, a traverse design tool has been developed that combines the functionality of a geographic information system with mission activity planning. The RP tool relies on the ability to use the time-varying parameters of sun and comm access together with static constraints (slope limits, block hazards, etc) to determine a viable and safe traverse corridor through space and time. By performing a Boolean "and" operation between relevant layers, through time, it is possible to forward-
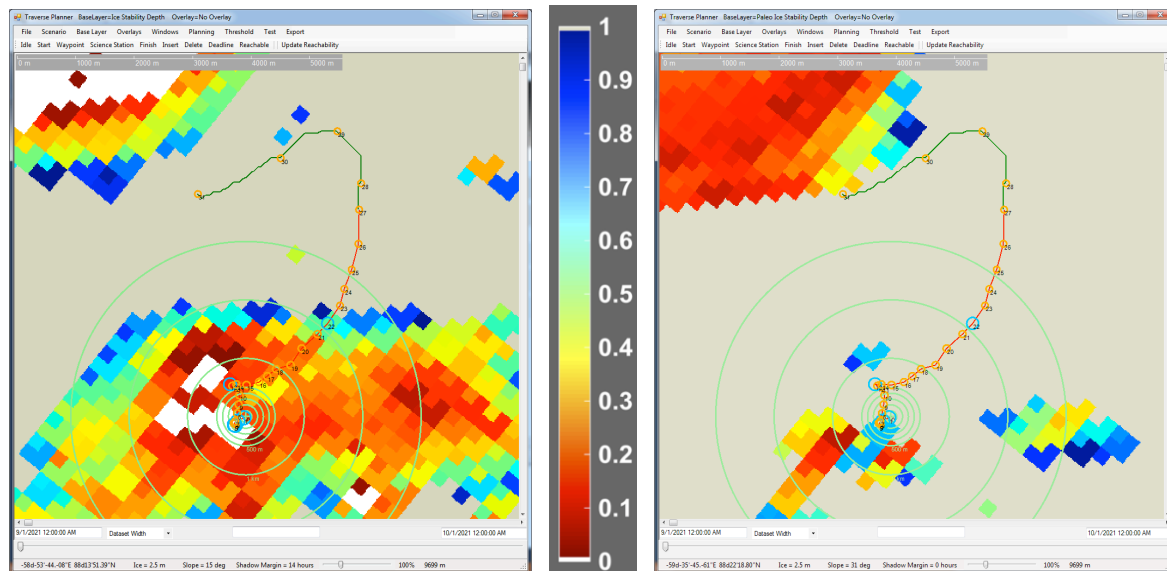
Fig. 1. Example of a traverse design for Hermit-A. (left) The visible layer is model depth to stable ice for the *present epoch*. (right) Visible layer showing model depth to stable ice for the *paleo-pole* from [3]. Scale bar is depth to the 1 mm/Ga ice loss level. Each map is ~8 km across, and ice stability depth pixels are 240 m.

flood the landing site area to establish such corridors. A key capability in this development is "reachability analysis": determining what areas can be attained (with margin) in a given period of time assuming selectable and realistic rover mobility capabilities and science activity durations. Rover performance and real-time decision-making on the ground will vary with the types of terrain, the level of hazard, and limits on situational awareness; these are incorporated into the tool as adjustable parameters based on testing and simulation.

Figure 1 shows an example of a traverse just to the east of the crater Hermite-A (87.9403N, -51.0219E). This multi-kilometer traverse covers all environmental zones for ice sequestration for the current pole and thermal conditions. It also examines the hypothesis that ice was preferentialy sequestered when the Moon's paleo-pole. RP will be able to address the issue of how early or late volatile sequestration has occurred, whether before or after true polar wander.

The RP traverse design tool is also currently being used to gauge the impact of various rover design attributes on achieving mission success at the four representative landing sites. Details will be provided.

References: [1] Colaprete, A., et al. (2010) *Science* 330.6003: 463-468. [2] Paige, D. A., et al. (2010) *Science* 330.6003: 479-482. [3] Siegler, M. A., et al. (2016) *Nature* 531.7595: 480-484.